

# SCIENCE FOR GLASS PRODUCTION

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## ROLE OF RECIPE AND TECHNOLOGICAL FACTORS IN FOAM GLASS FORMATION

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The temperature – time foaming parameters for glass batches are studied using a carbonate foaming agent (microcalcite). Methods are proposed for taking purposeful actions by means of technological and recipe factors (density and water absorption) on the characteristics of the foam glass.

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**Key words:** foam glass, foaming agent, microcalcite, density, water absorption.

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In the 1930s I. I. Kitaigorodskii developed a method of obtaining a porous material, called cellular glass or foam glass, from glass batch. To this day foam glass remains one of the most promising inorganic materials. It possesses a unique set of properties: together with excellent heat-insulation parameters and complete environmental, fire and hygienic safety foam glass is strong, has low average density as well as good moisture and frost resistance and is easy to install and work. Foam glass can be obtained with different volume weight from 100 to 700 kg/m<sup>3</sup>. As a rule, materials with volume weight below 250 kg/m<sup>3</sup> are used for heat insulation. Heat-insulation and construction products with density 250 – 400 kg/m<sup>3</sup>, combining an optimal compromise between heat conduction with mechanical strength, are also used in construction.

The conventional technology for producing foam glass is based on carbon foaming agents (soot, coke, anthracite, peat charcoal and so forth), which ensure foaming of finely disperse batches at temperature  $\geq 800$  °C [1 – 4]. However, the rapid price growth of energy carriers and high-temperature steels is making cellular glass an expensive “exotic” material that cannot compete with other types of heat insulation.

One way to solve this problem is to use carbonate technology for producing foam glass, making it possible to considerably lower energy consumption by lowering the foaming temperature by 80 – 100°C and replacing expensive high-temperature steel with low-alloy steel, significantly increasing the service life of furnaces and equipment.

Information research and experiments have established the main recipes and technological parameters that have the greatest effect on the quality of cellular material. First and foremost, these are the form and concentration of the foaming agent in the initial batch, dispersity and heat-treatment temperature and time at which foaming occurs. Among the widely available carbonate foaming agents comminuted natural marble (microcalcite) with 5 – 20  $\mu\text{m}$  particles was chosen.

The foam-glass technology is well-understood and consists in heating finely comminuted glass with a foaming agent added. The gas released at high temperature foams softened hot glass and imparts to it a cellular structure, which is strengthened by annealing during slow cooling.

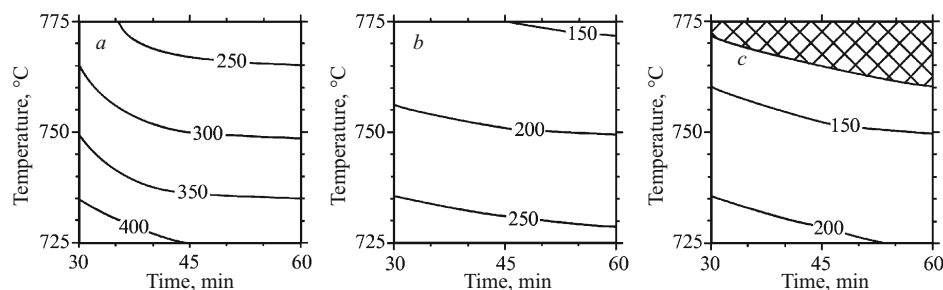
A full-factor experiment was performed to study the foaming process and find the optimal temperature – time conditions for the formation of foam glass. The variable parameters were as follows: the content of the foaming agent — microcalcite (1.5, 2.0 and 2.5 wt.%), temperature (725, 750 and 775°C) and heat-treatment time (30, 45 and 60 min); the response function was the density of the material obtained.

The experiments were performed according to the published temperature regimes for heating, sintering (foaming) and annealing the foam glass:

- heating from 20 to 600°C in 120 min;
- heating from 600°C to a prescribed temperature at the rate 5 K/min;
- soaking at a prescribed temperature for a prescribed period of time;
- cooling to 600°C at the rate 5 K/min;
- annealing the foam glass from 600 to 200°C at the rate 1 K/min.

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**Fig. 1.** Foam glass density versus foaming temperature and time with foaming agent content (wt.%): *a*) 1.5, *b*) 2.0, and *c*) 2.5. The foam glass density in  $\text{kg/m}^3$  is indicated on the curves.

After the experimental results were analyzed mathematically nomograms of the density of the foam glass were constructed in the form of isolines in the coordinate field of the parameters varied (Fig. 1).

Analysis of the nomograms shows that foam-glass with practically all densities of interest for heat insulation can be obtained in the experimental range of the variable recipe and technological parameters. As expected, foam-glass density decreases with increasing foaming temperature. The heat-treatment time also has an important effect on this indicator: the longer the duration, the lower the density of the article, but it is not advisable to increase the foaming time above 45 min, because there is no significant density change with increasing energy consumption.

For foaming agent content 1.5%, depending on the foaming time and temperature, foam glass with elevated density ( $230 - 400 \text{ g/cm}^3$ ) classed as heat-insulation – construction material is formed. For heat-insulation purposes  $150 - 270 \text{ kg/m}^3$  foam glass, obtained from batch with foaming agent content 2.0%, is preferable (Fig. 1*b*). Foam glass made from raw batch containing 2.5% microcalcite has an even lower density, but the structure of the material is significantly degraded because pore size increases and pores coalesce, which ultimately leads to substandard samples at elevated temperatures (hatched region in Fig. 1*c*).

In evaluating the effect of the foaming temperature on the quality of the foam glass it should be noted that at  $725^\circ\text{C}$ , because of weak gas generation and the high viscosity of the melted glass batch, a fine-pore material with elevated density is obtained (Fig. 2*a*). The probability of defects forming in the lower part of the samples and a nonuniform pore distribution in the volume increases. The structure of the material obtained at  $750^\circ\text{C}$  is characterized by a quite uniform porosity over the entire volume with  $0.5 - 1.0 \text{ mm}$  pores

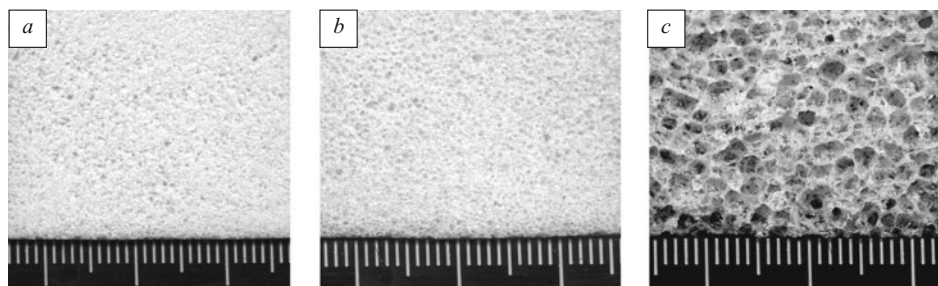
(Fig. 2*b*). When temperature is increased to  $775^\circ\text{C}$  the density of the foam glass decreases, but the pore size increases to  $2 - 3 \text{ mm}$  at the same time (Fig. 2*c*), and when the foaming agent is in excess the structure of the material breaks down.

The main drawback of carbonate foam glass is its high water absorption. For this reason a great deal of attention was devoted in the present work to studying the effect of the recipe and technological factors on this important characteristic of a heat-insulation material. The water absorption was studied following GOST 17177–94 with the sample completely submerged in water for 1 day [5]. To keep ‘crust’ forming during foaming from having an effect the foam-glass samples were worked on both sides.

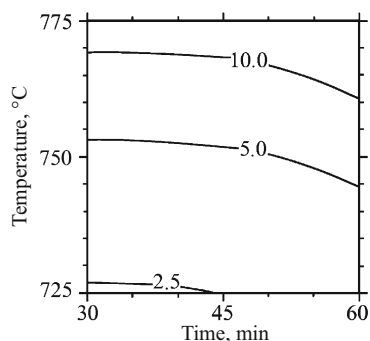
A nomogram of the water absorption of samples fabricated under different temperature – time conditions and containing 2.0% foaming agent is presented in Fig. 3. It is evident that the water-absorption isolines are inversely correlated with the density isolines (see Fig. 1*b*): the lower the density of the foam glass, the higher its water absorption. As the heat-treatment time increases the water absorption also increases; this is explained by the formation of a structure with communicating pores.

For foaming agent content 1.5% the water absorption is low and is determined primarily by the density of the foam glass:  $2.0 - 2.5 \text{ vol.}\%$  at density  $400 \text{ kg/m}^3$ ,  $3.5 - 4.0\%$  at  $300 \text{ kg/m}^3$  and  $5 - 6\%$  at  $250 \text{ kg/m}^3$ .

For foam glass made from batch with foaming agent content 2.5%, it was noted that the water absorption is higher,  $13 - 17\%$ , and is due to the large-pore structure and a higher fraction of open pores, characteristic for low-density articles obtained when the foaming agent is in excess. The lowest value corresponds to heat-treatment time 30 min and the highest value to 60 min. Such foam glass must be classified as sound absorbing [3].



**Fig. 2.** Structure of foam glass obtained at temperature  $725^\circ\text{C}$  (*a*),  $750^\circ\text{C}$  (*b*) and  $775^\circ\text{C}$  (*c*).



**Fig. 3.** Water absorption of foam glass versus the foaming temperature and time with foaming agent content 2.0%. The water absorption is indicated on the curves, %.

It is believed that porous heat-insulation materials with water absorption 5 vol.% and less are water-impermeable and can be used virtually without limitation. For water absorption > 5 vol.% measures must be taken to keep moisture from penetrating into the interior of the material. A combined analysis of the density (see Fig. 1b) and water-absorption (See Fig. 3) nomograms shows that for certain temperature – time conditions it is entirely possible to obtain 200 kg/m<sup>3</sup> or

more foam glass that is fully water-resistant and is used successfully for heat insulation.

In summary, studies have shown that material with prescribed density and water absorption can be obtained by varying the foaming time and temperature as well as the concentration of the foaming agent. The best quality foam glass with the required heat-insulation and density 200 kg/m<sup>3</sup> and water absorption < 5 vol.% can be manufactured with microcalcite content 2 wt.% at temperature 750°C and heat-treatment time 30 – 45 min.

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